Pressure safety approach for PIP-II cryogenic distribution system and cryomodules

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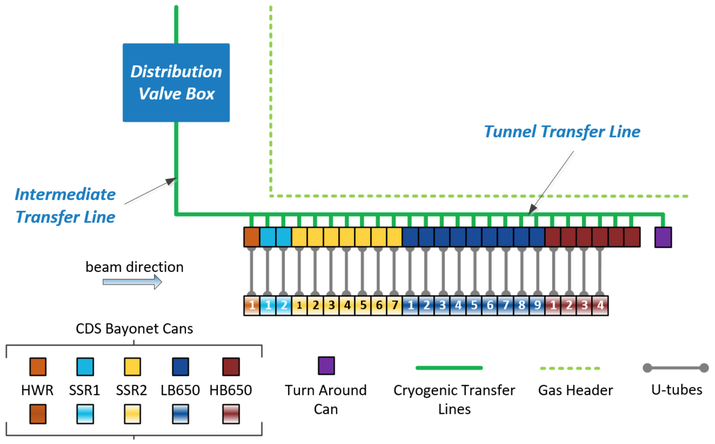
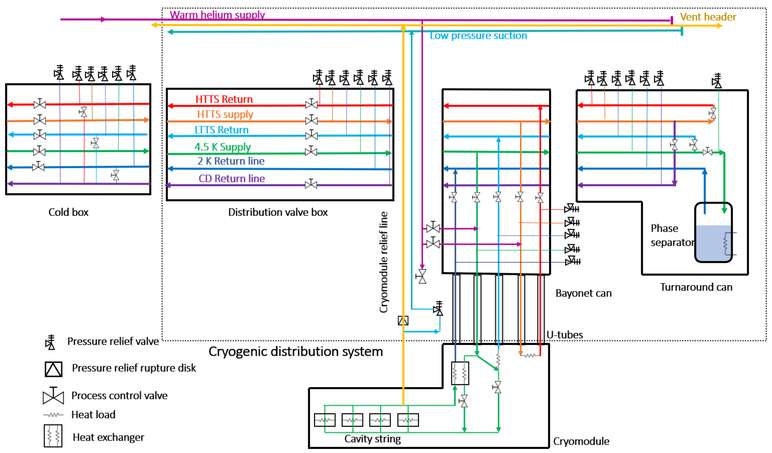
The Proton Improvement Plan-II (PIP-II) is a superconducting linear accelerator being built at Fermilab that will provide 800 MeV proton beam for neutrino production. The linac consists of a total of 23 cryomodules of 5 different types. Cooling is required at 2 K, 5 K and 40 K. The cryogenic system must provide protection from over-pressure by sizing pressure relief devices for all volumes and process lines. For the relieving occurring in the linac tunnel, flow must vent to outside to reduce oxygen deficiency hazard.



PIPII cryogenic distribution system and cryomodules schematic



PIPII cryogenic distribution system and cryomodules relief device locations

Method and assumptions

- Use standard methods (CGA S-1.3, EN4126).
- Take overpressure allowance for Loss of Vacuum (LOV) as 21% per Code (ASME) unexpected source external heat.
- Two ways to look at LOV: 1) accepted peak heat flux over surface or 2) limit heat input to energy from air inleak through feasible orifice.

Cryogenic distribution protection

- Air leaks through open DN80 vacuum evacuation port.
- Account for fraction of LOV heating the metal piping.

Heat load to CDS circuits during Loss of Insulating Vacuum (LOIV)

Circuit	Size	Heat Flux	Total Heat load distributed to He, from const flux	Heat transfer to He		Heat transfer to metal		TOTAL heat transfer
		[kW/m^2]	[kW]	[kW]	[%]	[kW]	[%]	[kW]
2k Return	DN250	6	42%	232	35	80	12	312
4.5k Supply	DN50	6	9%	51	8	11	2	63
LTTS	DN50	6	9%	51	8	11	2	63
HTTS Supply	DN50	0.23	0%	2	0	9	1	11
HTTS Ret & Shield, insulated	0.62 m dia	0.23	4%	20	3	0	0	20
HTTS Shield, uninsulated side	0.56 m dia	2.4	35%	191	29	0	0	191
CD	DN80	0.23	1%	3	0	0	0	3
SUM	-		100%	551	83	112	17	663

Cryomodule protection

- No credit taken for metal warming.
- Piping circuits- heat load from peak constant heat flux values.
- Cavities, cold- Air inleaks to beam tube vacuum through 60 mm coupler port. Apply peak heat flux for bare surface area 20 kW/m^2, which defines requirements.
- Cavities, warm- CDS TL is cold at nominal conditions. 4.5 K He supply valves mistakenly set full open, with return valve closed.

Venting relief devices to atmosphere

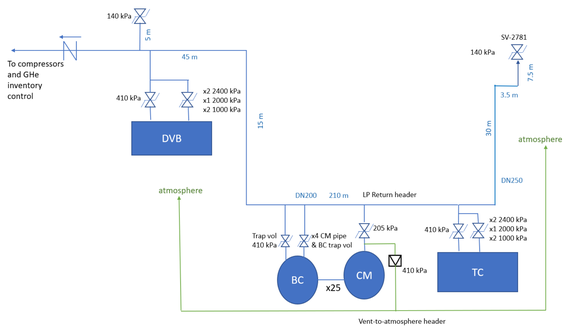
- Low Pressure Return- rated at 140 kPa. Collects reclosable SVs exhaust. Ensure backpressure not impacting the 2 K Return reliefs.
- Vent to Atmosphere header- Requirements call for RD flow to vent to outside, not into the tunnel. Utilize dedicated line open to atmosphere at the surface.

Helium relieving requirements

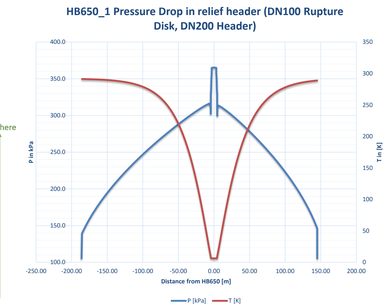
System	Circuit	Set Press [kPa]	Relieving Temperature [K]	Worst case condition	Heat Transfer to He [kW]	Helium flow requirement, each relief [kg/s]	SV size
CDS	2k Return	410	7.0	LOIV	232	4.78	100 x 150,two
CDS	4.5k Supply	2000	12.7	LOIV	51	0.34	20 x25, two
CDS	LTTS	1000	9.7	LOIV	51	0.57	20 x25, two
CDS	HTTS Supply	2400	40.	Cryoplant oversupply	Not applicable	0.055	20 x25,two
CDS	HTTS Return	2400	80.	LOIV	211	0.24	20 x25,two
CDS	CD Return	1000	80.	Cryoplant oversupply	Not applicable	0.10	20 x25, two
CM	4.5k Supply	2000	12.7	LOIV	3.23	0.047	15
CM	LTTS Return	2000	12.7	LOIV	10.6	0.16	15
CM	HTTS Supply	2400	40.	LOIV	43.9 half of HTTS total	0.20	15
CM	HTTS Return & shield	2400	80.	LOIV	43.9 half of HTTS total	0.10	15
CM	2k volume-cold	410	7.0	LOBV	216	8.9	100
CM-HWR	2k volume-cold	275	6.0	LOBV	166	8.5	100
CM	2k volume-warm	205	300	TL Oversupply with return closed	Not applicable	0.27	80 x 100

Cryogenic distribution vacuum protection

- CDS vacuum jacket DN700, MAWP 150 kPa.
- Vacuum segmentation: 71 m for surface, 104 m and 106 m tunnel.
- Consider internal line spontaneous rupture, 4.5 K Supply worst case. Spills contents. Plant supplies full capacity. Conservative.
- Fluid expands from external and shield warming.
- Results: Total relief area per segment defined. Propose two 70 mm reliefs on each Tunnel Transfer Line Bayonet Can.



Low Pressure Return and relief device venting to atm



Vent to atmosphere performance

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